IDCORE Symposium

27th March, 2017

University of Exeter

The University of Edinburgh

University of Strathclyde

Contents

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Introduction

Welcome to the second annual IDCORE Symposium at the University of Edinburgh. The Industrial Doctoral Centre for Offshore Renewable Energy is an initiative of the Energy Technologies Institute and the Research Councils UK (RCUK) Energy Programme.

It is a consortium of the Universities of Edinburgh, Exeter and Strathclyde, along with the Scottish Association for Marine Science and HR Wallingford. Together, these leading UK offshore energy research institutions offer a world-class Engineering Doctorate (EngD) programme in Offshore Renewable Energy.

The EngD is a doctoral-level research and training programme, equivalent in academic standing to a conventional PhD but achieved through industrially-focussed research designed to produce graduates with a sound understanding of the business implications of industrial research activity.

All IDCORE projects are industry-based, proposed and directed by sponsoring companies, and supported by a panel of academic supervisors. Focus can be on any aspect of offshore renewable energy, with the aim to make an original contribution to company procedures and practises, or to knowledge in general.

This Symposium is intended as a showcase for the work currently being carried out by our Research Engineers in the Wave, Wind and Tidal industries, featuring both talks and poster presentations on projects ongoing around the British Isles.

Schedule

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Fraser Ewing, DNV GL

10:10 *An Integrated Data-Management Method for Offshore Wind Reliability Analysis*
Alex Koltsidolpoulos-Papatzimos, EDF Energy R&D UK Centre

10:35 *Control and Instrumentation of an Integrated Wave Energy Array*
Calum Kenny, Albatern

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11:15 **Theme Two: Risk and Uncertainty**

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Optimum Electrical Topologies and Control Strategies for Interconnected Wave Arrays
Sarah Acheson, Albatern

Resistive Control of a Point Absorber Using Reinforcement Learning
Enrico Anderlini, Wave Energy Scotland

Experimental Investigation of Array Effects for a Mechanically-Coupled WEC Array
Anthony McDonald, Albatern

13:20 Poster Session Two: Tidal

Modelling Kites for Power Generation
Kristin Luttik, Scottish Association for Marine Science

First Steps Towards a Multi-Parameter "Location & Layout" Optimisation Tool for Arrays of Floating Tidal Platforms
John McDowell, Sustainable Marine Energy

Cont.

Minimising Marine Energy Risk by Understanding Uncertainties
Sunny Shah, Black & Veatch

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The Implications of Wind Resource Assessment Uncertainty on Debt Sculpting in Offshore Wind Farms
Esteve Borras-Mora, EDF Energy R&D UK Centre

Risk Management of Offshore Wind Project Development
Jack Paterson, EDF Energy R&D UK Centre

Modelling the Physics of Failure of Subsea Umbilical Cables
David Young, ORE Catapult

Simulation of Environmental Factors in the FloWave Facility and their Influence on Device Behaviour
Stephen Young, FloWave

14:00 **Keynote Address - Alan Mortimer, SgurrEnergy**

14:45 **Theme Three: Physical and Numerical Modelling**

14:45 *Using an Advanced Multi-Directional Combined Wave-Current Environment to Test Offshore Renewable Energy Devices*
Donald Noble, FloWave

15:10 *PLAT-O#2 at FloWave: A Validation of ProteusDS at Modelling Response of a Taut-Moored Tidal Platform at Tank-Testing Scale*
Ilie Bivol, Sustainable Marine Energy

15:35 Coffee and Tea

15:50 **Theme Three: Physical and Numerical Modelling (Cont.)**

15:50 *Loading Analysis of a Ducted, Open Centre Tidal Stream Turbine*
Steven Allsop, EDF R&D LNHE

16:15 *Multibody Dynamics Approaches for Modelling Wave Energy Converters*
David Ogden, Innosea

16:40 *Field-Measured Water Particle Kinematics to Validate a Linear Model for Tidal Flows*
George Crossley, DNV GL

17:05 Closing Comments

17:15 Drinks Reception

Keynote Speaker

Alan Mortimer (BSc Hons, MSc, CEeng, MIMechE)

Alan Mortimer graduated from Glasgow University in 1987 with an Honours degree in Aeronautical Engineering. After four years at James Howden & Co. Ltd. in Glasgow, Alan joined ScottishPower, working in renewables development. His roles included Head of Wind Development where he developed the strategy for, and led the development of, a wind portfolio including Whitelee Windfarm – which now at 539MW is Europe's largest onshore windfarm.

In his subsequent role as Head of Policy for ScottishPower Renewables (SPR) Alan was responsible for managing policy and strategic issues whilst maintaining responsibility for identifying new business opportunities in renewables, including SPR's role in technology development programmes such as the Offshore Wind Accelerator, and marine renewables. He identified and developed the 10MW Islay Tidal Demonstration Array project and securing consents for the project (a world first), and managed SPR's interests in the Orcadian Wave Project utilising Pelamis wave technology.

He has advised the Scottish Government and Scottish Enterprise on supply chain needs and managed activities to develop the marine supply chain to maximise Scottish content.

Alan joined SgurrEnergy in 2013 as Director of Innovation where his role involves extending the company's renewable energy activities in onshore wind, offshore wind, solar, wave, tidal, heat and transport with greater involvement in technology development and innovation. The aim of all of this work is to enhance performance and reduce the costs of renewable technologies in support of the rapidly-growing global market.

Abstracts

Theme One: Reliability and Operations Maintenance

Reliability Prediction for Offshore Renewables: Data-Driven Insights
Fraser Ewing

The UK's Contract for Difference (CfD) auction takes place in April of this year and, because of the removal of technology specific ringfencing, wave and tidal will now be directly competing with offshore wind for governmental financial support for projects developed in the early 2020s. Offshore wind is already considerably below its strike price of £105/MWh (some projects as much as 50%) so in order to compete in the auction wave and tidal must also demonstrate that they can go considerably below their own strike prices of £310/MWh and £300/MWh respectively. Reliability is a key cost driver for wave and tidal devices and hence accurately quantifying and assessing device reliabilities is critical for the successful commercialisation of the industry. Without improvements in reliability and hence reductions in operation & maintenance (O&M) costs, the industry will struggle to reach a competitive Levelised Cost of Energy (LCoE). At present, due to the nascent stage of the industry and commercial sensitivities there is very little available reliability field data. This presents an issue: how can the reliability of ORE's be accurately assessed and predicted with a lack of specific reliability data?

ORE devices largely rely on the assessment of surrogate data sources for their reliability assessment. To date there are very few published studies that empirically assesses the failure rates of offshore wind turbines. The applicability of surrogate data sources to the ORE environment is critical and needs to be more thoroughly evaluated for a robust ORE device reliability assessment. Experiences from the onshore wind industry and the emerging offshore wind data have shown that the drive train is an area of critical importance with respect to reliability. Hence this paper will focus on critical components of the drive train including the pitch system, frequency converter and generator. This paper tests two commonly held assumptions used in the reliability assessment of ORE devices. Firstly, the constant failure rate assumption that underpins ORE component failure rate estimations is addressed. By using high fidelity onshore wind field data to empirically assess the application of the constant failure rate assumption for several critical drive train components, this paper uses probabilistic methods to challenge an idea that forms a central part of ORE reliability prediction.

Secondly, a model that is often used to assess the reliability of onshore wind components, the Non-Homogeneous Poisson Power Law Process (PLP) model is empirically assessed and trend tested to determine its suitability for use in ORE reliability prediction.

This paper suggests that pitch systems, generators and frequency converters cannot be considered to have constant failure rates when analysed via nonrepairable methods. Thus, when performing a reliability assessment of an ORE device using non-repairable surrogate data it cannot always be assumed that these components will exhibit random failures. Secondly, this paper suggests when using repairable system methods, the PLP model is not always accurate at describing the failure behaviour of onshore wind pitch systems, generators and frequency converters whether they are assessed as groups of turbines or individually. Thus, when performing a reliability assessment of an ORE device using repairable surrogate data both assumptions and their potential impact on the analysis should be carefully considered.

An Integrated Data Management Method for Offshore Wind Reliability Analysis
Alex Koltsidopoulos-Papatzimos

A significant amount of operation and maintenance (O&M) data are being generated daily from offshore wind farms, including a variety of monitoring systems, maintenance reports and environmental sources. The challenge with having a wide variety of data sources with different temporal and format characteristics, is that a significant effort is required to identify evidence that supports a root cause analysis (RCA) of a turbine fault. In addition, the organization of the O&M data flow does not lend itself to support easy reporting of the O&M key performance indicators. Since the offshore wind industry is growing rapidly, there is a need to better understand and manage the O&M data generated. This study demonstrates a novel integrated data management system that combines all the O&M data from an offshore wind farm and proves that the proposed RCA framework, based on this integrated platform, can lower O&M costs, by reducing the number of visits to the turbines. It also provides failure rates for sub-assemblies and looks at the failure distribution within the wind farm. The results of this research will be of interest to offshore wind farm developers and operators to streamline and optimize O&M planning and activities for their assets.

Control and Instrumentation Topologies for an Integrated Wave Energy Array

Calum Kenny

Albatern Ltd's WaveNET is an integrated wave energy array consisting of multiple 'Squid' wave energy converters. Prototype data collection is vital to the development of the 6 Series device, with the aim to understand critical failure modes and improve reliability. A robust and reliable Control and Instrumentation (C&I) system provides the framework for performance and condition monitoring, and improving device controllability. However, cost and power constraints, in addition to the scalability of network architecture, present a challenge in designing a C&I architecture that is appropriate for the application.

The research study describes the development of a C&I system for an integrated wave energy array. A review of available instrumentation is performed, informing the cost, power and data acquisition requirements of each sensor. Next, a Failure Modes and Effect Analysis is undertaken to identify the critical failure modes of the Squid 6 Series device, this is used to identify measurement priorities and provide a set of monitoring solutions. To support this, a scalable, interconnected Network Architecture is proposed, employing a Distributed Control System that enables distributed Input/Output modules and fast communication via industrial Ethernet. Two configurations have been provided, one for commercial deployments and the other with the aim of enhanced data collection. Improved data collection will aid the development of a reliability centred maintenance strategy, but focus must be drawn to reducing O&M costs and designing out failure in order to reduce the long term Levelised Cost of Energy.

Theme Two: Risk & Uncertainty

Offshore Wind Installation Risk - A Comparative Assessment for UK Offshore Rounds One, Two and Three

Jack Paterson

Marine operations play a pivotal role throughout all phases of a wind farm's life cycle. In particular uncertainties associated with offshore installations can extend construction schedules and increase the capital expenditure (CAPEX) required for a given project. Installation costs typically account for approximately 30% of the overall project cost. This study considers the installation modelling for UK offshore Wind Rounds one, two and three using EDF's ECUME I software tool. This facilitates Monte Carlo simulation with the embedded models as shown in *Figure 1* (*overleaf*) and outputs time-domain predictions for the completion of key installation phases. The results are provided under user specified exceedance probabilities, which are commonly used by developers to assess their risk preferences and project viability.

In this study, three installation strategies were defined using typical vessel spreads and operational limits, which resemble a mean approach adopted across each of the offshore wind development rounds. By varying key windfarm characteristics such as distance to shore and the number of turbines, an assessment of vessel performance was completed for each round by reviewing recorded durations predicted by the software. This revealed that the capabilities of construction vessels have generally improved with time, yet some installation phases such as turbine and cable installation have experienced significant challenges. From the results obtained, it appears that the delays experienced during the wind turbine assembly phase can be reduced as more capable vessels arrive on the market and that further improvements with cable installation vessels may further increase overall installation rates.

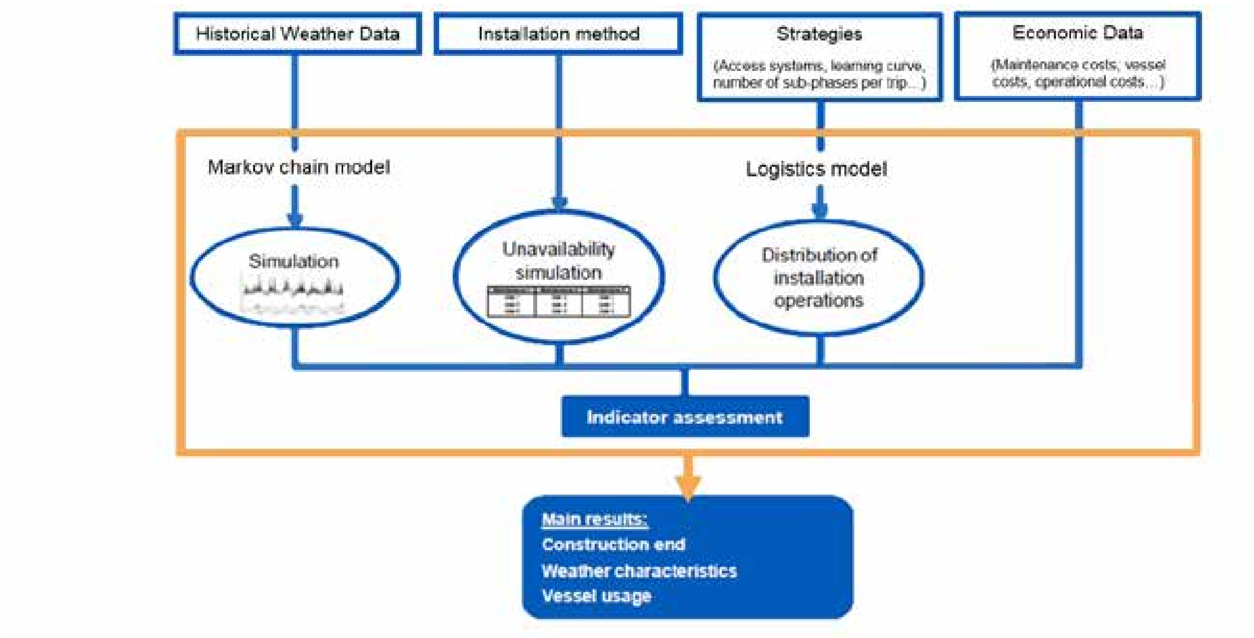

Figure 1: Model Inputs and Architecture of the ECUME I

Comparison of Yield Uncertainty Propagation Methods for Tidal Energy

Sunny Shah

High investment risk is a key barrier to the commercialisation of the nascent tidal energy sector. The pre-construction annual energy production (AEP) estimate of a tidal energy project is an important investment decision metric and the uncertainty in the AEP is a significant component of the overall risk profile of a typical tidal energy project. An increased confidence in the yield uncertainty estimate is one pathway to increasing investor confidence. The yield uncertainty estimate depends on the characteristics of the underlying individual uncertainties (such as uncertainty in resource, plant performance and losses) and on the method used to combine the individual uncertainties. The aim of this paper is to quantitatively assess two methods – ISO – Guide to the Expression of Uncertainty in Measurement (GUM) and Monte Carlo Analysis (MCA) for propagating and combining uncertainties, and to recommend the most suitable method for tidal energy projects. Representative wind and tidal energy projects are analysed to identify the fundamental reasons why ISO-GUM, validated and widely used for wind energy projects, is less widely valid for tidal applications. A sensitivity study is used to demonstrate that the fundamental ISO-GUM assumption of a linear tidal resource-yield function for small variations in resource is invalid for resource uncertainties larger than approximately 4-11% depending on the project characteristics. Beyond this limit, ISO-GUM overestimates the P90 yield by at least 2% and can therefore give a falsely optimistic view of the investment risk in a project. Finally, MCA is shown capable to validly sample skewed input distributions. This effect may be significant if a small number of highly skewed uncertainties are dominant. MCA is therefore recommended for tidal energy projects given that all projects in the near future can be considered to be early stage with uncertainties likely to exceed the ISO-GUM validity threshold shown.

Analysis of Tidal Energy Yield Uncertainties Through Lessons Learned from Wind Energy Yield Assessments

Rob Clayton

The wind energy industry is approximately 30 years ahead of the tidal stream industry. Experience has shown that wind resource assessment is complex and subject to inherent uncertainty. There is an historic tendency to overestimate wind farm performance which adversely affects investment, impacting on sector growth. It is important to quantify and minimise uncertainties of annual energy production, as the measure of uncertainty will influence the commercial performance & attractiveness of the project. Nowadays, wind resource assessment methods allow developers and investors to determine the uncertainty in project return estimates. As the tidal stream industry moves towards array development, similar approaches are needed to evaluate uncertainty and minimise risk. This research proposes a transfer of existing experience of estimating uncertainties from the established processes within the wind energy industry to the nascent tidal stream energy industry, based on similarities in approaches to calculating the annual energy yield for both industries.

This research focusses on identifying gaps in the current knowledge of tidal energy uncertainties and primarily addresses two major uncertainties: historic & future resource estimation; and spatial variation of flow models from extrapolation of data. Uncertainties in tidal energy yield estimations are presently larger than those of wind energy due to the relative development of industry measurement methods and the amount of data acquired from operational wind farms. The tidal industry has the opportunity to accelerate its understanding of uncertainties by learning from the experience gained in the wind industry. This work investigates where the most significant uncertainties lie within tidal resource assessment and suggest methods to reduce them.

Theme Three: Physical and Numerical Modelling

Using an Advanced Multi-Directional Combined Wave-Current Environment to Test Offshore Renewable Energy Devices

Donald Noble

Physical scale model testing is an important development tool, used extensively to study the behaviour of marine devices, vessels and structures in a controlled environment prior to deployment at sea. Whilst specific guidance on developing and testing offshore renewable energy devices has been published over the past decade, it has limitations in terms of advanced environmental conditions for testing. The body of existing guidance is reviewed, and initial suggestions offered for additional test conditions that may be considered in later stages of model testing. This focuses on testing in combined waves and currents, particularly the multi-directional aspect thereof, which is now possible in facilities such as the FloWave Ocean Energy Research Facility at The University of Edinburgh. The advanced test conditions proposed all have potential to affect both the power capture performance and loading on the device, so should be considered for tidal stream turbines, wave energy convertors, and floating offshore wind turbines, but their applicability will depend on the specifics of the device and deployment site. Realistic waves, and wave-current interactions particularly, are complex non-linear processes that can be difficult to model numerically, and thus developers may benefit from the increased learning carried out in controlled conditions on a relatively inexpensive model, prior to conducting real-world tests in the ocean.

PLAT-O#2 at FloWave: A Validation of ProteusDS at Modelling Response of a Taut-Moored Tidal Platform at Tank-Testing Scale

Ilie Bivol

Floating tidal generators have the potential to power island communities with economical, renewable and fully predictable electricity. Subsea, taut-moored generators enable optimization of capture depth, survivability and O&M costs. One such prototype in development is PLAT-O#1 [1] and PLAT-O#2 (*Figure 2, overleaf*), developed by Sustainable Marine Energy.

A sufficiently accurate estimation of offshore structure response (motion and time loads) is essential for designing a tidal stream device that survives installation, generation and storms in service. Two distinct numerical methods are available: dynamic analysis tools, e.g. ProteusDS [2], and Computational Fluid Dynamics (CFD) codes. The ProteusDS code computes platform *loads*, based on Morison and Froude-Krylov, and *motion* from mooring lines, modelled as lump-mass elements. Key limitations are: no account for fluid-structure interaction or shielding, and the need for empirical hydrodynamic coefficients. The finer CFD method offers a solution to these, but its large processing need deems it impractical for a first-pass study. To inform the optimum tool, this paper explodes the reach of ProteusDS in providing desired confidence in modelling tidal platform responses.

Before full-scale application, standard engineering practice dictates initial validation of numerical methods in the tank. A 1:17 scale, physical model of PLAT-O#2 was tested at the FloWave basin [3], Edinburgh, using combined currents and waves up to 4.5m/s and 4m heights, respectively. The platform was tested with turbines absent, present and in storm position. The full details are published in [4], which presented an initial validation study of ProteusDS and the tank testing results. The presented paper builds on this study, using an alternative modelling approach and a higher comparison resolution, for further insight into the robustness of the model.

The previous study [3] focused solely on the extremes and mean responses of the platform; extrapolated to, and modelled at, *full* scale. The findings gave comparable loads, however significantly different motions; this is justified by scaling errors and numerical model assumptions. In this follow-up study, instantaneous response timeseries are compared in terms of both amplitude and frequency. The scaling error contribution is removed by numerical modelling like-for-like at *tank* scale. For accurate scaling of mooring stiffness in the experiment, springs were used. These act as point, rather than distributed, stiffness and affect motion down the line. This facet is not captured previously and is investigated in this work through separate modelling of the springs.

This paper uses the tank data for separate combinations of device configurations, i.e. platform only and platform with turbines, and environments (current and waves) to calibrate coefficients and allocate error to the contributing parts.

In summary, this paper will present:

- Tank-scale comparison of measured and predicted (by ProteusDS) response timeseries, line loads and platform motions, in magnitude and frequency, of a 1:17 scale PLAT-O#2 model tested at the FloWave basin.
- Testing of dynamic analysis software ProteusDS in terms of robustness and limitations in capturing hydrodynamics at model scale.
- A systematic calibration of prescribed drag coefficients for best physical and numerical agreement.

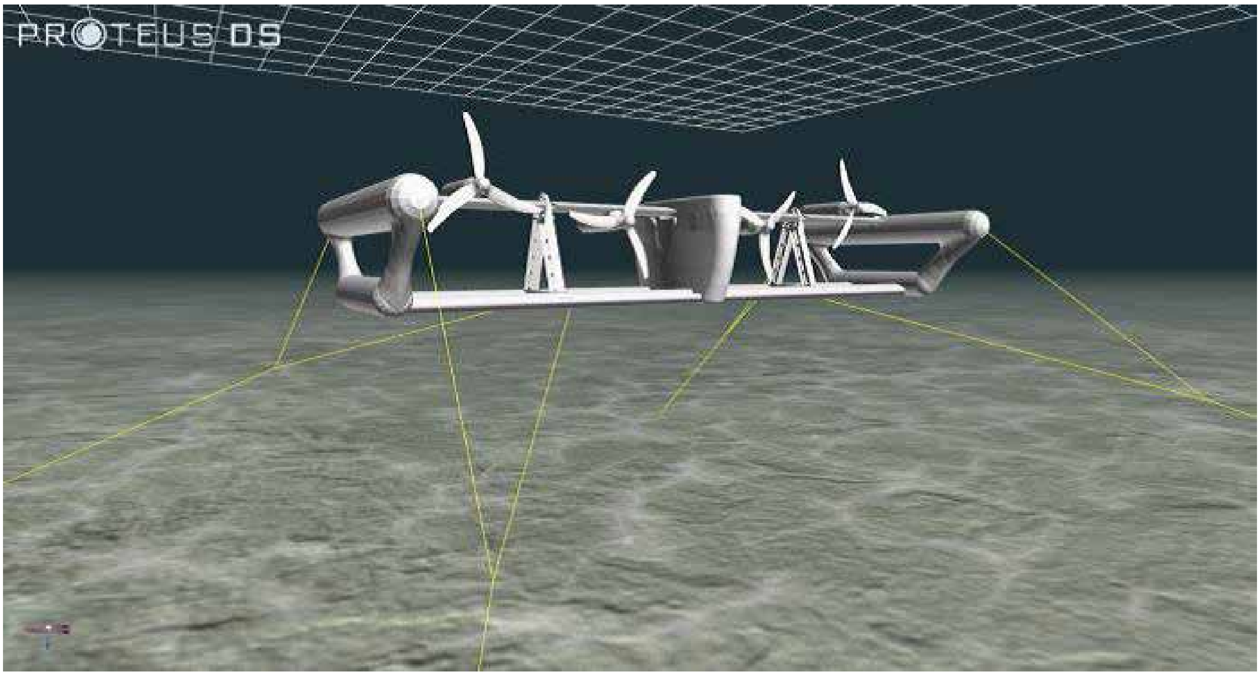

Figure 2: 3D visualisation of PLAT-O#2 platform and mooring lines [4]

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4. P. Jeffcoate, F. Fiore *et al*, *Comparison of Simulations of Taut-Moored Platform PLAT-O using ProteusDS with Experiments*, Proceeding of the 3rd AWTEC, Singapore, Oct 24-28, 2016.

Loading Analysis of a Ducted, Open Centre Tidal Stream Turbine

Steven Allsop

The Paimpol-Bréhat pilot tidal array is an EDF 'energies marines' venture, consisting of two x 500 MW rated OpenHydro turbines, currently under deployment off the coast of Brittany, Northern France. This is a measurement campaign, in order to evaluate the capabilities of the ducted and open centre type devices for future investment. Numerical models are designed to assess the behaviour of a turbine at various degrees of detail, the selection of which is dependent on the intended application. Relatively simple but well established models based on the blade element momentum theory (BEMT) method allow analysis of rotor forces, and have shown successful application to three-bladed, bare turbines.
This presentation details the development of a BEMT which incorporates an analytical adjustment to account for the momentum changes in augmented flow through a duct. The power and thrust predictions are validated against data from a more complex computational fluid dynamics (CFD) study, where excellent agreement is seen for the majority of operational velocities.

A significantly shorter computational demand is seen for the Ducted BEMT model, in the order of CPU-minutes, in contrast to CPU-days reported in the CFD study. This suggests better suitability to performing 3rd party engineering assessments such as blade reliability under numerous different operating conditions.

The model is limited to steady, frozen inflow conditions, and neglects dynamic interactions such as inertia and added mass. However, non-uniform velocity profiles can be prescribed, which cause blade load distributions to vary as the turbine completes each revolution. Current extensions to the work include development of a structural analysis tool to assess the blade fatigue life under cyclic loading from non-uniform inflows.

Multibody Dynamics Approaches for Modelling Wave Energy Converters

David Ogden

Numerical models can be pivotal to the development of a wave energy converter (WEC), allowing a large number of design iterations to be tested on a computer. By analysing key parameters such as power extraction and system response for many design iterations, the WEC developer can better understand their concept and hone in on improved designs. However, because there are such a wide range of WEC concepts, many developers must either create and validate their own in-house software or perform no numerical modelling at all - potentially leading to sub-optimal designs. This project builds on Innosea's existing time-domain WEC modelling tool, InWave [1] to improve its functionality.

The current code features an in-house multibody solver based on Featherstone's Articulated Body Algorithm (ABA) [2] - one of the fastest & most efficient multibody dynamics algorithms available. However, it has some limitations with regards to functionality and is inherently unable to model many important features such as closed mechanical loops, non-holonomic constraints and flexible bodies.

Here we show an alternative approach to multibody dynamics simulation, which can be used to model a wider range of motion constraints (including non-holonomic constraints), combine different types of constraints and create multibody systems on the fly - avoiding the awkward parametrisation process required by the ABA. This method is based on 'enforcing constraints' (as opposed to 'reducing coordinates') and is called the Lagrange Multiplier Method (LMM).

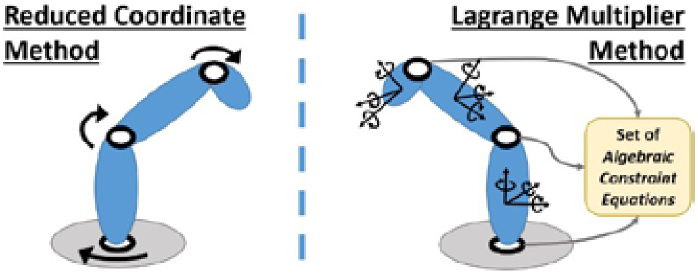

Figure 3: Overview of Multibody Dynamics Methods.

We show how a third party LMM-based code, HOTINT [3] has been coupled to hydrostatic and hydrodynamic solvers to model WECs in InWave (*Figure 4, overleaf*) and present validation results and comparisons to InWave's existing multibody dynamics algorithm (in terms of theory, implementation, performance and accuracy). We also demonstrate how this approach enables the modelling of a WEC with closed mechanical loops. Finally, we discuss the interest of both approaches for WEC modelling.

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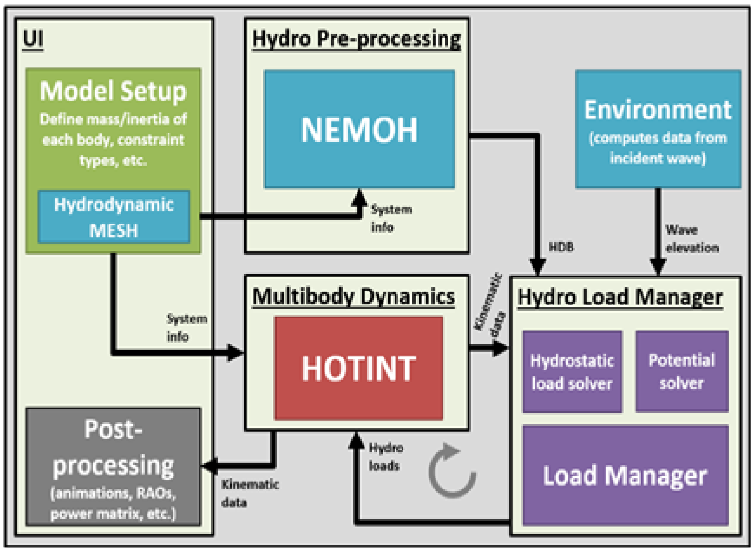

Figure 4: Software Overview

Field-Measured Water Particle Kinematics to Validate a Linear Model for Tidal Flows

George Crossley

Field measured water particle kinematics are used to validate a linear model for tidal flows, combining waves and turbulent current. Using a 'Virtual' Acoustic Doppler Profiler (VADP), to measure the simulated flow, direct comparisons are made between model and site kinematics recorded using Acoustic Doppler technology.

Acoustic Doppler technology is versatile in the measurement of sea conditions; however, the accuracy of the technology can be limited when measuring the small-scale fluctuations caused by waves and turbulence. The VADP is used to sample a simulated tidal flow enabling 'beam-to-beam' comparison of model and field kinematics, subsequently eliminating the assumptions made about the flow when resolving to three dimensional, earth natural unit velocities.

Flow data containing simultaneous measures of subsurface velocity and surface elevation from a UK tidal site for development was measured with a five-beam TRDI Sentinel V deployed in the winter of 2014/2015. The configuration of the TRDI ADP setup and its positioning at the site is input into the Virtual ADP. Specific sea conditions are selected from the data and fed to the flow model which simulates subsurface velocities based on the current, wave and turbulent conditions. Velocities are recorded by the Virtual ADP and compared with real subsurface velocities measured at the site in terms of velocity spectra at a range of depths.

Separating the individual kinematic components of the flow, the interaction between waves and turbulent currents throughout a range of conditions is established for the site under investigation. Significant conclusions are drawn on the effectiveness of a linear model for simulating combined wave-current flows.

The interaction between waves and currents of varying speed and direction is found to be quasi-linear with a minor empirical correction to the linear model for wave-current interaction proving suitable at depths considered for tidal energy exploitation. The furthering of this study will include analysis of data from other sites for comparison with, and validation of the tidal flow model.

Poster Presentations

Wave

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Resistive Control of a Point Absorber Using Reinforcement Learning
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The Implications of Wind REsource Assessment Uncertainty on Debt-Sculpting in Offshore Wind Farms
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Notes

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